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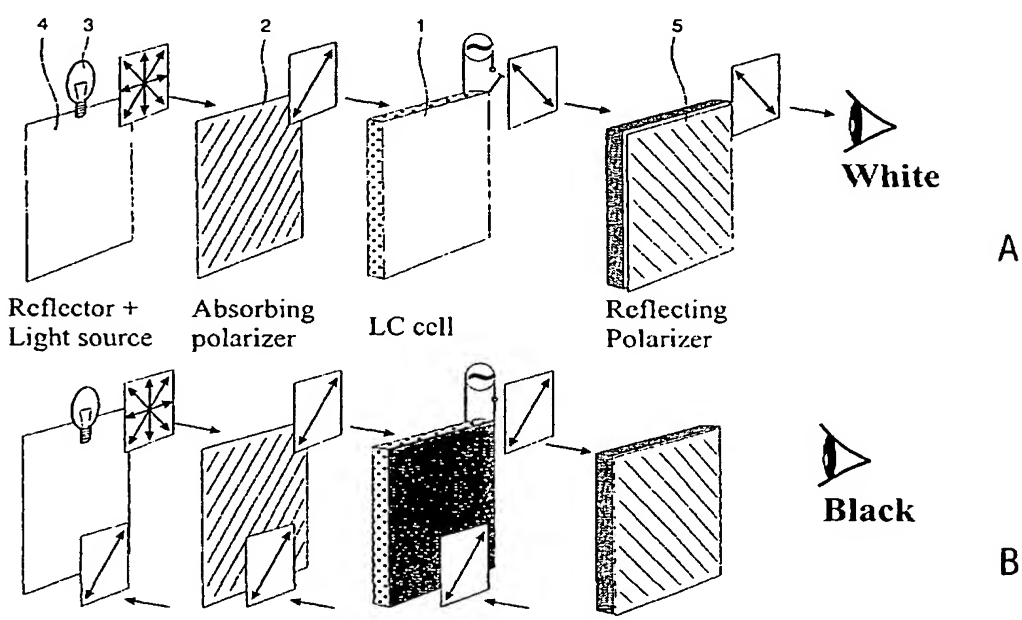
(54) Title: TRANSMISSIVE DISPLAY DEVICE WITH REFLECTIVE POLARIZER ARRANGED ON THE VIEWER SIDE



(57) Abstract: This invention relates to a transmissive display device, comprising a plurality of optical shutter elements (1, 11 21) as well as a polarization selective reflection/transmission device arranged on the viewer side of the display device and a reflective light-redirecting device (4, 14, 24). Essentially each of said shutter elements is switchable between a reflective and a transmissive state. Furthermore, said reflective light redirecting device (4, 14, 24) is arranged to redirect reflected light towards ambient optical shutter elements.

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TRANSMISSIVE DISPLAY DEVICE WITH REFLECTIVE POLARIZER ARRANGED ON THE VIEWER SIDE

This invention relates to a transmissive display device, comprising a plurality of optical shutter elements as well as a reflective light redirecting device, and specifically it relates to liquid crystal display devices comprising a reflective back panel.

Many different kinds of displays are currently available on the market. Traditionally, cathode ray tube displays have been the common choice for applications such as computer displays and television sets. Cathode ray tube technology does however result in large appliances and has other drawbacks, which has resulted in a decrease in the use of CRTs in favour of displays based on other technologies. One technology that currently is growing rapidly is displays based on liquid crystal technology (LCDs). These kinds of displays have many advantages compared with traditional CRTs, e.g. their flatness, thickness and power consumption.

However, LCD technology has also some disadvantages compared with the CRT. For example, CRTs show an effect referred to as sparkling, i.e. the effect that a small white displayed area will produce more light, if the rest of the display becomes darker, i.e. the display load becomes lower.

The upper curve in fig 1 shows this effect. This curve shows the measured luminance of a white test square on a CRT as a function of the average luminance level of the complete input signal, i.e. the display load. In a dark scene, the luminance output has a fixed value that is relatively high (~400cd/m^2). When the average luminance level of the input signal exceeds a fixed value, the luminance output decreases. In fact, what happens is that at a point, the average tube current becomes too high and therefor, it is limited. This is seen in the lower curve in fig 1. It shows the average luminance value of the CRT output picture versus the average luminance value of the input signal. First, the output increases linear with the input signal. Then at said fixed value, i.e. at a critical display load, the current is limited and the average luminance output remains constant.

For an LC display, the luminance value of the white pixels does not depend on the contents of the rest of the picture. It remains constant at a relatively low level, as may be

seen in fig 2. The average luminance output of the display increases linearly with the average luminance levels of the input signal.

The above description of the sparkling phenomenon is only directed towards white pixels. However, when the tube current is limited, the gain of the video amplifier in the CRT has decreased, which affects all luminance levels in the same manner. This has been shown by testing for a plurality of different grey levels.

The above-described sparkling behaviour has an attractive effect on the image quality: For example, stars on a dark sky will appear very bright. This is an effect that people appreciate, and moreover have got used to, due to the wide spread use of CRT displays. An LC display totally lacks this effect, as best seen in fig 2, and could therefor be considered as looking rather dull compared with a CRT display.

One straight forward way of solving the above described problem with LC displays is to copy the CRT characteristics by means of video processing, and consequently decrease the light output at higher display loads. However, this means that, when displaying a bright scene, the LC display will produce less light than it is capable of, as shown in fig 3. Moreover, this method requires a video processing system, which may be expensive.

Consequently, it is an object of the present invention to provide a transmissive display having a display load dependency similar to a CRT, without the above-mentioned drawbacks.

A further object of the invention is to provide a display that enhances the brightness of bright parts in a displayed image.

Yet another object of the invention is to provide a display having a brightness of bright parts of a displayed image that increases when an increasing part of the rest of the display displays dark scenes.

One further object of the invention is to provide a display that may be easily manufactured using standard components.

Yet one object of the invention is to provide a display, furthermore demonstrating a good daylight contrast.

These and other objects are achieved in accordance with the invention by a transmissive display device, wherein each of said shutter elements are switchable between a reflective and a transmissive state and in that said reflective light redirecting device is arranged to redirect reflected light towards ambient optical shutter elements. Thereby, light which is not used to mediate the picture to the viewer's eye, such as light intended for a

closed or "black" shutter element, will be reflected back into the display, for use at another position. In a display device in accordance with prior art, such light would be absorbed by a front polariser, and this light would be lost. Furthermore, since this light is reflected back into the panel, it will be reflected against the reflective back panel, and will therefore be recycled until transmitted, resulting in a high efficiency.

According to a preferred embodiment the transmissive display device have optical shutter elements being formed by a liquid crystal display device, comprising a liquid crystal layer as mentioned by way of introduction, whereby a polarisation selective reflection/transmission component is arranged on a viewer side of said liquid crystal layer. By including a component between the LC-layer and the viewer that transmits certain polarisations while reflecting others, it is possible to accomplish a display in which light not used to mediate the picture to the viewer's eye, such as light travelling through a "black" pixel, will be reflected back into the display, for use at another position. As above, in a display device in accordance with prior art, such light would be absorbed by a front polariser, and this light would be lost. Furthermore, since this light is reflected back into the panel, it will be reflected against the reflective back panel, and will therefore be recycled until transmitted, resulting in a high efficiency LC display. Preferably, said light redirecting device is a reflective back panel, suitably having a built-in diffuser function, whereby reflected light may be redistributed to other shutter elements, areas or pixels of the display. Thereby, when the displayed picture has a few bright spots on a dark background, more light will be transmitted through the bright pixels, since a large quantity of light has been reflected and redistributed. Consequently, a liquid crystal display showing a sparkling effect is achieved.

Suitably, said polarisation selective reflection/transmission device is a reflective polariser, and furthermore a light source, such as a backlight panel, is preferably arranged between said liquid crystal layer and said reflective back panel. Preferably, also a second polariser is arranged between the light source and the liquid crystal layer.

In accordance with a preferred embodiment of the invention, said polarisation selective reflection/transmission device is a cholesteric liquid crystal layer, being a rather well tested and simple component. However, since a cholesteric liquid crystal layer is designed to reflect either right- or left-handed essentially circularly polarised light, a $\lambda/4$ plate is preferably arranged between the liquid crystal cell and said cholesteric liquid crystal layer. However, in accordance with another preferred embodiment of this invention it is also possible that said liquid crystal layer exhibits $\lambda/4$ retardation, in which the orientation of the optic axis is switchable. Furthermore, said liquid crystal layer is preferably switchable

between $\lambda/4$ retardation and $3\lambda/4$ retardation. In accordance with yet another preferred embodiment of this invention, said polarisation selective reflection/transmission device is a stack of layers, having alternately isotropic and anisotropic refractive index.

Furthermore, in accordance with another preferred embodiment, a further absorbing polariser is arranged on the viewing side of said polarisation selective reflection/transmission device. Thereby, it is possible to achieve a display in which ambient light, falling onto said display from the viewer's side, is either absorbed in the display device or reflected by the reflective back panel, and consequently is reused within the panel for the display of pictures. Consequently, a display having a good daylight contrast is achieved. For the reasons stated above, a further $\lambda/4$ plate is preferably arranged between said polarisation selective reflection/ transmission device and said absorbing polariser, in the case that said polarisation selective reflection/transmission device is a cholesteric liquid crystal layer.

In exemplifying purpose, the invention will hereinafter be described in closer detail, with reference to presently preferred embodiments thereof illustrated in the accompanying drawings, wherein:

Fig 1 is a diagram showing the measured relation of CRT luminance output of a white square versus the average luminance level of the input signal, according to prior art.

Fig 2 is a diagram showing the LCD luminance output of a white square versus the average luminance level of the input signal, according to prior art.

Fig 3 is a diagram showing the luminance of an LCD, when CRT behaviour is mimicked by means of signal processing.

Fig 4a and 4b shows a schematic arrangement in accordance with a first embodiment of the invention, in a white and in a black mode, respectively.

Fig 5a and 5b shows a schematic arrangement in accordance with a second embodiment of the invention, in a white and in a black mode, respectively.

Fig 6a and 6b shows a schematic arrangement in accordance with a third embodiment of the invention, in a white and in a black mode, respectively.

Fig 7 shows a schematic arrangement in accordance with a fourth embodiment of the invention, in a white and in a black mode, respectively, having an improved daylight contrast.

Fig 8 shows a schematic arrangement of the fourth embodiment of the invention in accordance with fig 7, in a white and in a black mode, respectively, showing recycling or absorption of ambient light.

Fig 9 is a schematic drawing showing the beam path through a monochrome LC display in accordance with an embodiment of the invention.

Fig 10 is a schematic drawing showing the beam path through a colour LC display in accordance with an embodiment of the invention, having a cholesteric layer within the LC-cell.

Fig 11 is a schematic representation of the light recycling process in an LC display in accordance with the invention.

As well known in the prior art, images in LCD-panels are generated by means of selective light absorption in a polariser. For a white pixel, light is transmitted, and is allowed to reach the eye of an observer. For dark pixels, the light is absorbed in the display, and consequently never reaches the eye of the observer. This invention is based on the realisation that, if it would be possible to redistribute the light that is not directly used by the dark pixels, to other pixels, instead of letting the light be absorbed for the dark pixels, a non-linear behaviour, similar to the sparkling effect in a CRT would be obtained. For a dark scene, the pixels of a bright area would then be able to receive light from the surrounding dark pixels. Consequently, that area would emit more light that the same area would do, if surrounded by other bright areas, in which the light has already been transmitted to the observer. In accordance with the invention this distribution of light may be realised in a number of different ways, which will be described hereinafter.

A first embodiment of this invention is shown in fig 4a and 4b. In this embodiment a driven liquid crystal cell 1, such as a twisted nematic liquid crystal cell, is placed between crossed polarisers, a front polariser 5, on the observer side of the liquid crystal cell 1, and a back polariser 2. Said front polariser 5 is a reflecting polariser having the effect that light having one polarisation is transmitted, while light having an orthogonal polarisation is reflected. Consequently, such a component for example separates unpolarised incident light into two components, each being linearly polarised, whereby the first component is transmitted, while the other one is reflected. A reflective polariser may for example be realised by using cholesteric layers or alternating stacks of layers having isotropic and anisotropic refractive indexes.

On the backside of the display, a backlight is arranged 3 (illustrated as a single light source on fig 5), and behind it, a diffusing reflector plate 4.

The benefit of having a reflective polariser 5 at a viewer side of the LCD cell 1 is that this kind of system reflects light from dark parts of the screen back to the backlight 3,

where it is reflected and diffused by said reflector plate 4. This increases the brightness of the effective backlight, and for darker scenes, the brightness increase is larger than for brighter scenes. Thereby a sparkling effect, as described above, is generated.

As described above, a cholesteric reflective polariser may be used in the above-described configuration of the invention. This embodiment of the invention is shown in fig 5, in which the same parts have the same reference numbers as in fig 4, however pre-noted with a numeral "1", and will therefore not be described again here. However, in this application, one need to assure that the light, hitting the cholesteric reflective polariser has a circular polarisation. The most straightforward way of achieving this is by inserting a quarter wave plate 16 between the liquid crystal cell 11 and a cholesteric reflective polariser 15, as shown in fig 5a and 5b. In the embodiment of the invention showed in fig 5a and 5b, light is only transmitted through the cholesteric layer, when the liquid crystal cell has been switched to the "white" state by external electronics (not shown) and the electrodes (not shown) placed on opposite sides of said liquid crystal cell 11. When the liquid crystal layer has been switched to the "black" state, light will be reflected back towards the light source, as shown in fig 5b. This reflected light will follow its way back through the liquid crystal cell, passing the absorbing back polariser 12 and thereby reaching the light source 13. Behind the light source 13, said diffusing reflector plate 14 is arranged, which reflects and redistributes the light in order to make it available for other parts of the screen. One simple way of achieving this is by using a diffuse reflector that reflects and scatters the light back into the display construction. In other words, light that is not used by the dark pixels of the display is recycled and made available for other screen parts. Furthermore, the same amount of light might be reflected in "dark" pixels a plurality of times, before being transmitted through a currently bright pixel. A schematic drawing of this phenomenon is shown in fig 11. This drawing shows how much light theoretically may be transmitted from the display, with consideration taken to reflection and redistribution losses. In theory, the resulting gain factor, due to internal reflection will be:

$$gain = \sum_{i=0}^{\infty} \eta^i (1-l)^i = \frac{1}{1-\eta(1-l)}$$

wherein η is the absorption factor for each reflection and l is the transmission level. Without light recycling, the output from the display would be η*l.

In the above described second embodiment of the invention, a separate quarter-wave retardation plate 6 is needed in order to convert the linearly polarised light, coming from the liquid crystal cell 1, to circularly polarised light, before it hits the cholesteric reflective polariser 5. However, in accordance with a third embodiment of this invention, this retardation plate may be omitted, by including its functions in the liquid crystal cell itself. This embodiment is shown in fig 6a and 6b, in which the same parts have the same reference numbers as in fig 4, however pre-noted with a numeral "2", and will therefore not be described again here. There are several ways of providing such functions in the liquid crystal cell 21. A simple way of achieving this is by using a non-twisted cell, that is switchable between a ¾ wavelength retardation and a ¼ wavelength retardation. Another way of achieving the same result is by providing an in-plane switching cell, for example with various ferroelectric LCD modes with a quarterwave retardation and the optical axis at +45 and –45°, respectively, for the two polarities of voltage pulses. Further, it is also possible to achieve the same optical effect by applying well-designed and well dimensioned twisted nematic layers in said liquid crystal cell, on per se known manner.

The above-described embodiments illustrate the basic principles of recycling light otherwise absorbed in dark pixels of a display. However, when using the above displays under daylight circumstances, ambient light from the viewers side of the system will be reflected by the reflective polariser, resulting in a degradation in daylight contrast. For most applications a high daylight contrast is desired. This is achieved by the following fourth embodiment of the invention, as shown in fig 7 and 8. This embodiment is basically a modification of the embodiment shown in fig 6, but the basic idea is applicable to any one of the embodiments disclosed above. Due to the similarities with fig 6, the same reference numbers are used for the same parts, and a full description of each part is omitted. In this embodiment an absorbing linear polariser 28 is added on the viewer side of the device, as shown in fig 8. Due to the fact that the absorbing polariser 28 at the viewing side is linear, it is necessary to further add a quarterwave plate 27 between the cholesteric reflecting layer 25 and the absorbing polariser 28. The light transmission for an LC-cell dark state and white state, respectively, is shown in fig 10, and is essentially identical with the transmission described above, with reference to fig 6.

However, with the embodiment in accordance with fig 7 and 8, incident ambient light will not be reflected. Fig 8 shows what happens to ambient light that falls on the LC display according to this embodiment. When the liquid crystal cell 21 is in the white state, ambient light will reach the backlight 23 and will be reflected and diffused by the

reflecting plate 24. This means that this light will be useful in the display, and might be internally reflected until transmitted, as described above, and shown in fig 11. When the liquid crystal cell 21 is in its black state, light will not reach the backlight, as shown in fig 8, but will be absorbed by the polariser. Therefore no light will be reflected from the LC panel, and black pixels will therefore remain black when hit by daylight. As a conclusion, this embodiment results in a light recycling display, having excellent daylight contrast properties.

Many modifications and variations of the above-described embodiments of the invention are possible within the scope and spirit of this invention, as defined by the appended claims.

For example, the embodiments described above all relate to monochrome displays. One example of a beam path pattern through a display, as shown in fig 7, is shown in fig 9. In this beam path picture, one can see that light hitting a "white" LC pixel is transmitted, while light hitting a "black" pixel is transmitted back into the display. However, the above-described technology is just as applicable when it comes to colour displays. In order to obtain a colour display, a colour filter must be added. In order to avoid so-called parallax problems, the colour filters is preferably placed close to the LC cell, and preferably inside the LC cell, i.e. between the electrodes of the cell (not shown). This configuration is shown in fig 10. In this construction three layers are arranged in the LC cell, namely the LC layer, the cholesteric layer, and the colour filter, in sequence, with the colour filter closest to the viewer. By placing the layers in this order, essentially all light is reflected if the pixel is in a dark state. It is possible to exchange the position of the colour layer and the cholesteric layer. However, in that case 2/3 of the light would be absorbed by the colour filter, and the light recycling would get a decreased efficiency, which is undesirable. Other configurations using the basic idea of light recycling, in accordance with the claims are possible. Other modifications of the above-described optical components, together forming the inventive system, are also evident for a person skilled in the art.

CLAIMS:

1. A transmissive display device, comprising a plurality of optical shutter elements as well as a reflective light redirecting device (4, 14, 24), characterised in that essentially each of said shutter elements is switchable between a reflective and a transmissive state and in that said reflective light redirecting device (4, 14, 24) is arranged to redirect reflected light towards ambient optical shutter elements.

2. A transmissive display device as set forth in claim 1, wherein said optical shutter elements are formed by a liquid crystal display device comprising a liquid crystal layer (1, 11, 21), and a polarisation selective reflection/transmission device (5, 15, 25) is arranged on a viewer side of said liquid crystal layer (1, 11, 21).

3. A display device as set forth in claim 2, wherein said light redirection device is a reflective back panel (4, 14, 24).

4. A display device as set forth in claim 3, wherein said reflective back panel (4, 14, 24) has a built-in diffuser function.

5. A display device as set forth in any one of the claims 2-4, wherein said polarisation selective reflection/transmission device (5, 15, 25) is a reflective polariser.

6. A display device as set forth in any one of the claims 2-5, wherein a light source (3, 13, 23), such as a backlight panel, is arranged between said liquid crystal layer (1, 11, 21) and said reflective back panel (4, 14, 24).

7. A display device as set forth in claim 6, wherein a second polariser (2, 12, 22) is arranged between the light source (3, 13, 23) and the liquid crystal layer (1, 11, 21).

8. A display device as set forth in any one of the claims 2-7, wherein said polarisation selective reflection/transmission device (5, 15, 25) is a cholesteric liquid crystal layer.

9. A display device as set forth in claim 8, wherein a $\lambda/4$ plate (16) is arranged between the liquid crystal cell (11) and said cholesteric liquid crystal layer (15).

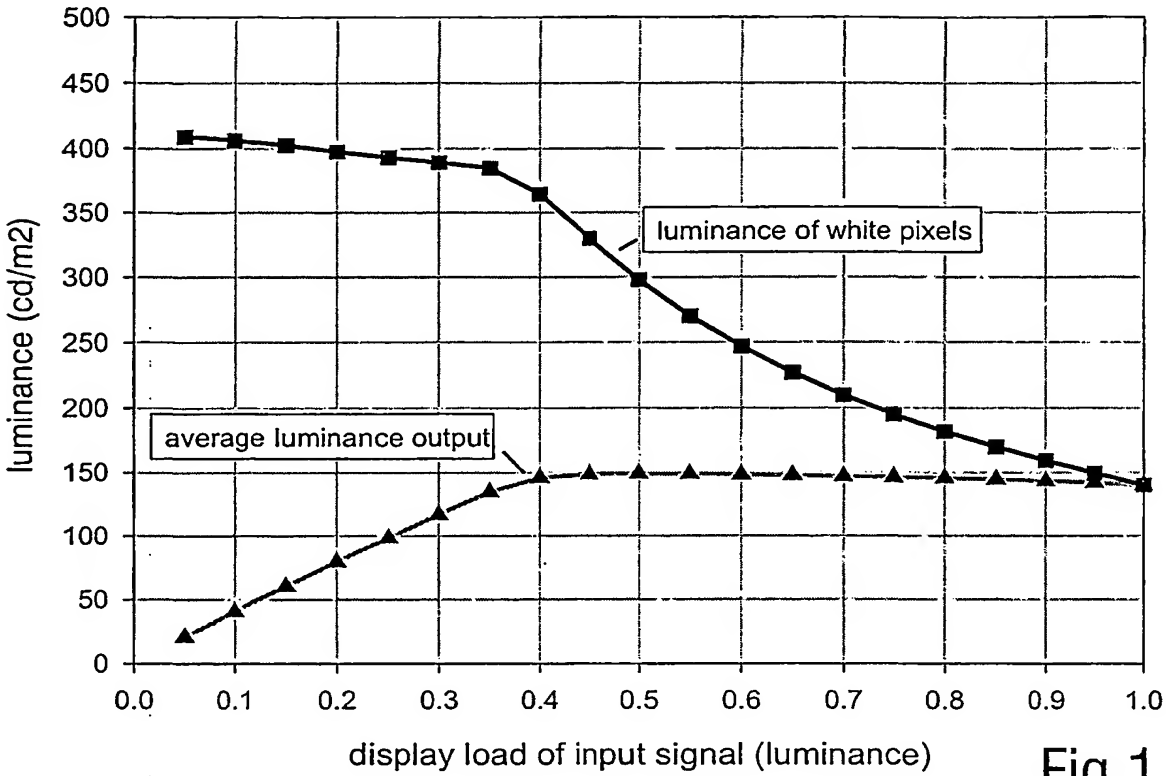
10. A display device as set forth in claim 8, wherein said liquid crystal layer (21) is switchable between $\lambda/4$ retardation and $3\lambda/4$ retardation.

11. A display device as set forth in claim 8, wherein said liquid crystal layer (21) exhibits quarterwave retardation, in which the orientation of the optic axis is switchable.

12. A display device as set forth in any one of the claims 2-8, wherein said polarisation selective reflection/transmission device (5) is a stack of layers, having alternately isotropic and anisotropic refractive index.

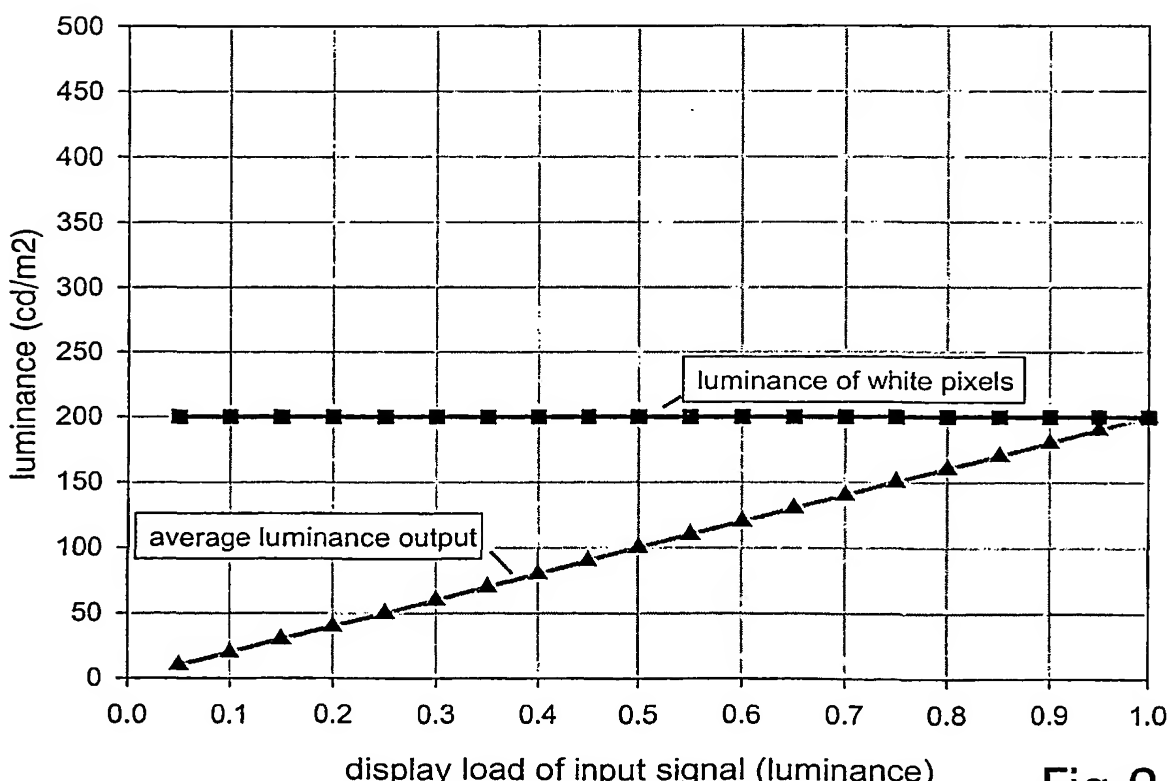
13. A display device as set forth in any one of the claims 2-12, wherein a further absorbing polariser (28) is arranged on the viewing side of said polarisation selective reflection/transmission device (25).

14. A display device as set forth in claim 13, wherein a further $\lambda/4$ plate (27) is arranged between said polarisation selective reflection/ transmission device (25) and said absorbing polariser (28), in the case that said polarisation selective reflection/transmission device (25) is a cholesteric liquid crystal layer.



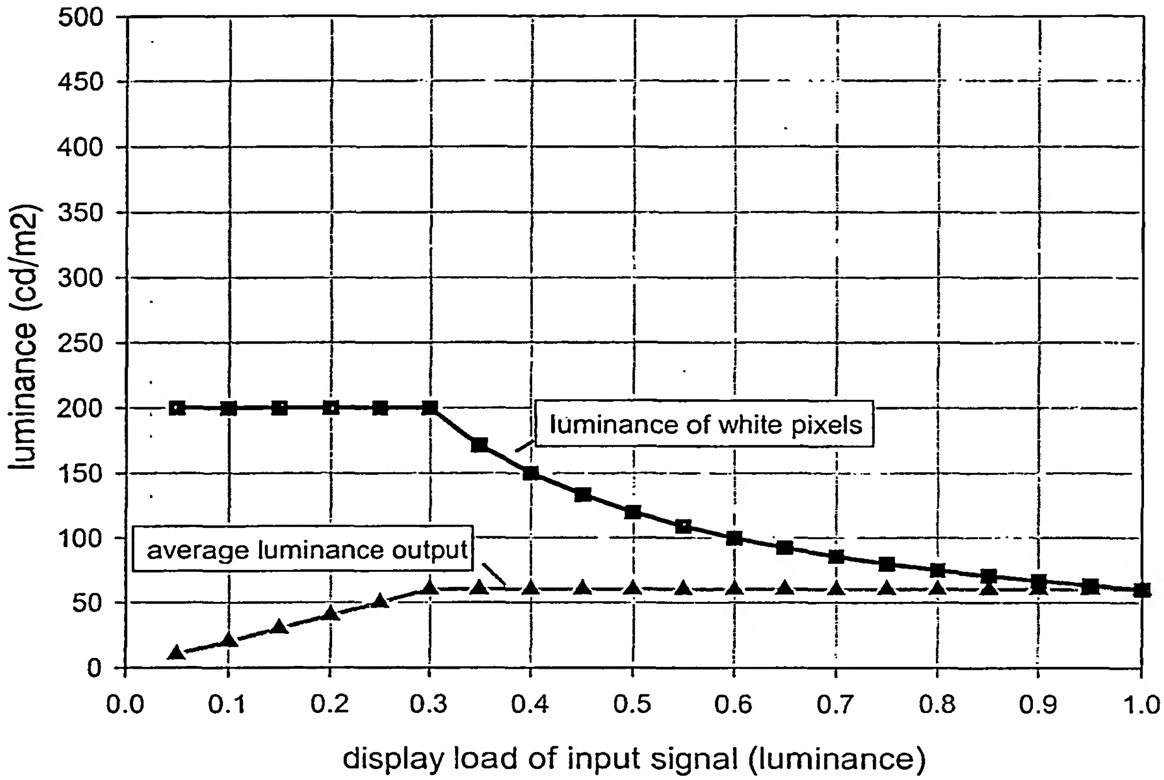
500
450
400
350
300
250
200
150
100
50
0
luminance (cd/m2)
luminance of white pixels
average luminance output
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
display load of input signal (luminance)

Fig.1



500
450
400
350
300
250
200
150
100
50
0
luminance (cd/m2)
luminance of white pixels
average luminance output
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
display load of input signal (luminance)

Fig.2



500
450
400
350
300
250
200
150
100
50
0
luminance (cd/m2)
luminance of white pixels
average luminance output
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
display load of input signal (luminance)

Fig.3

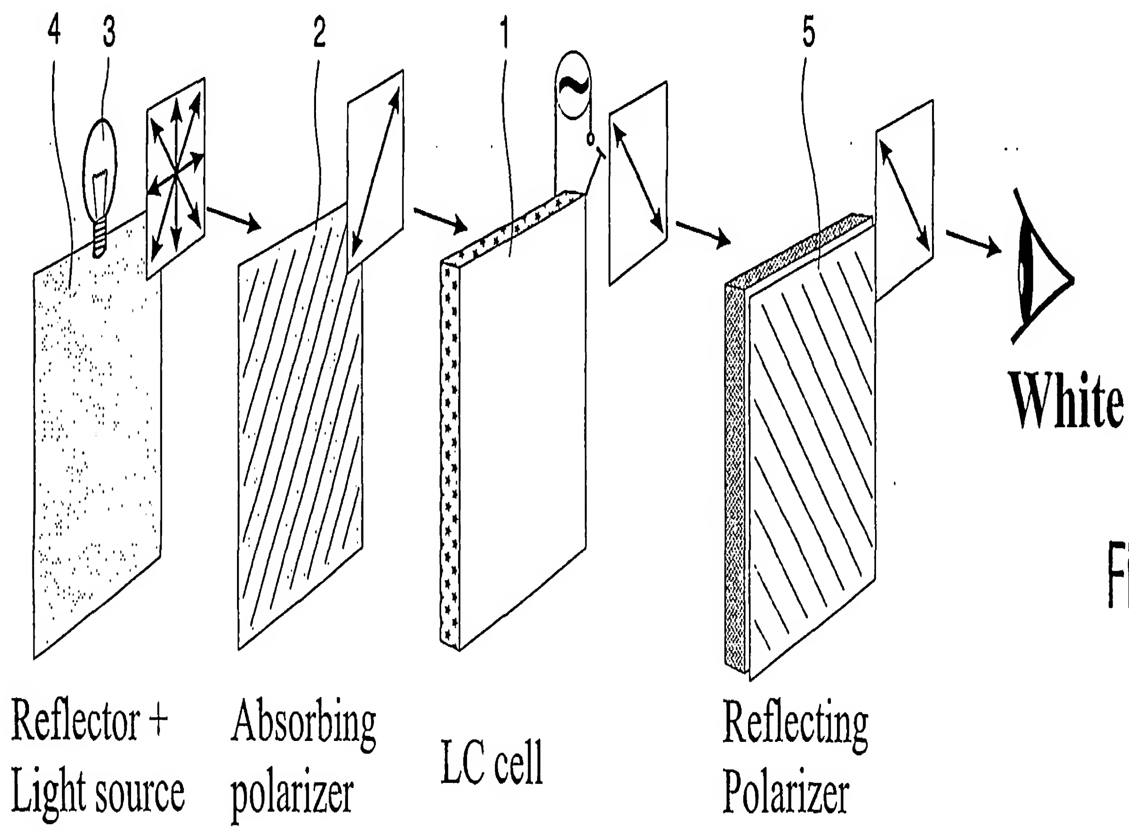

4
3
2
1
5
White
Reflector +
Light source
Absorbing
polarizer
LC cell
Reflecting
Polarizer

Fig.4A

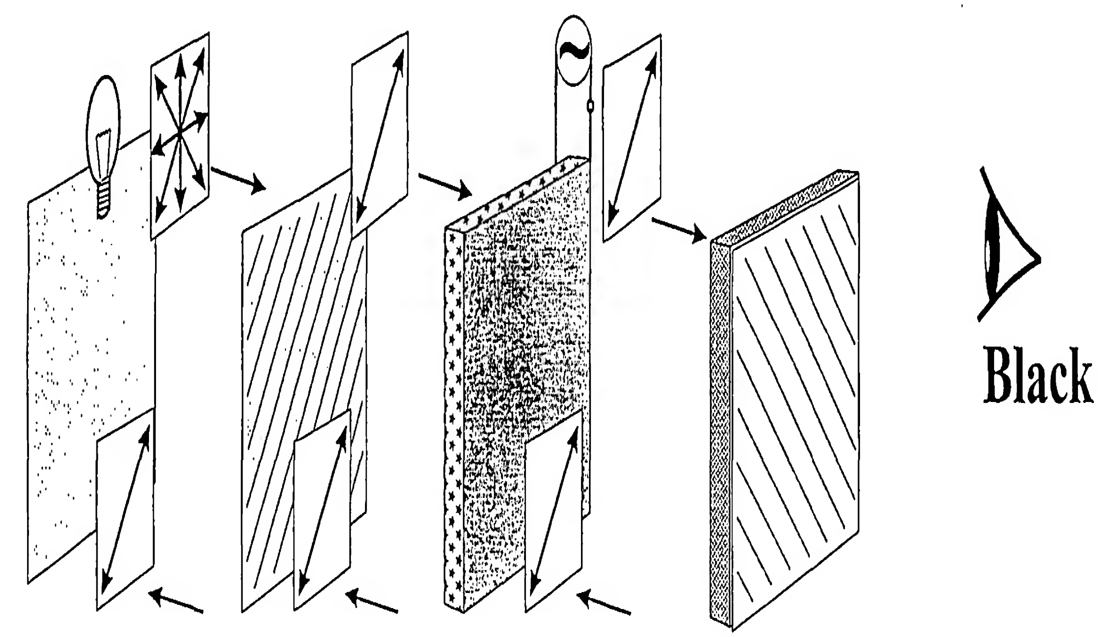

Black

Fig.4B

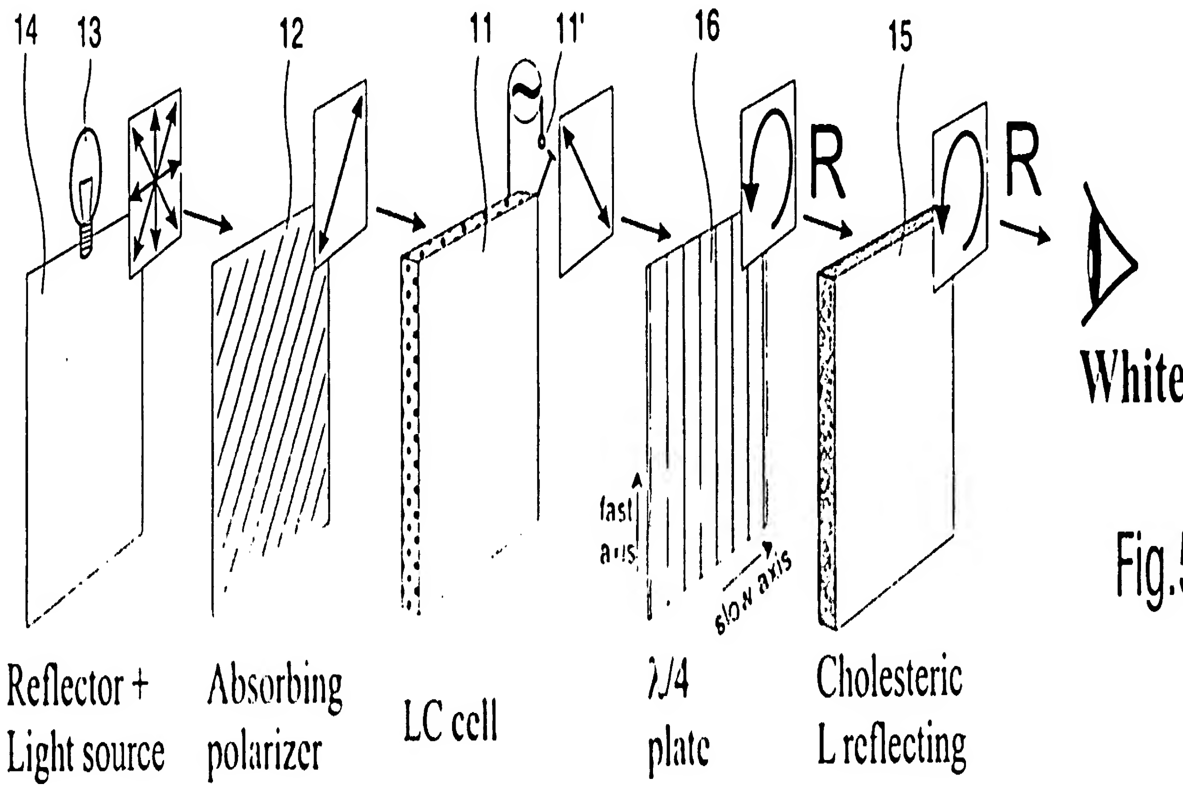

14
13
12
11
11'
16
15
R
R
fast axis
slow axis
White
Reflector + Light source
Absorbing polarizer
LC cell
λ/4 plate
Cholesteric L reflecting

Fig.5A

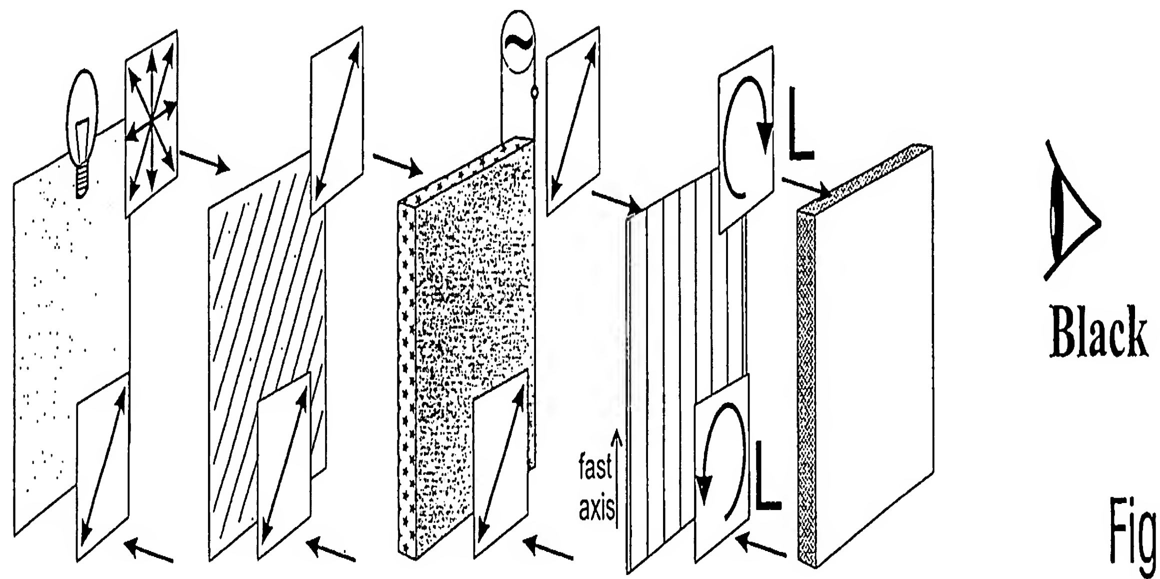

L
L
fast axis
Black

Fig.5B

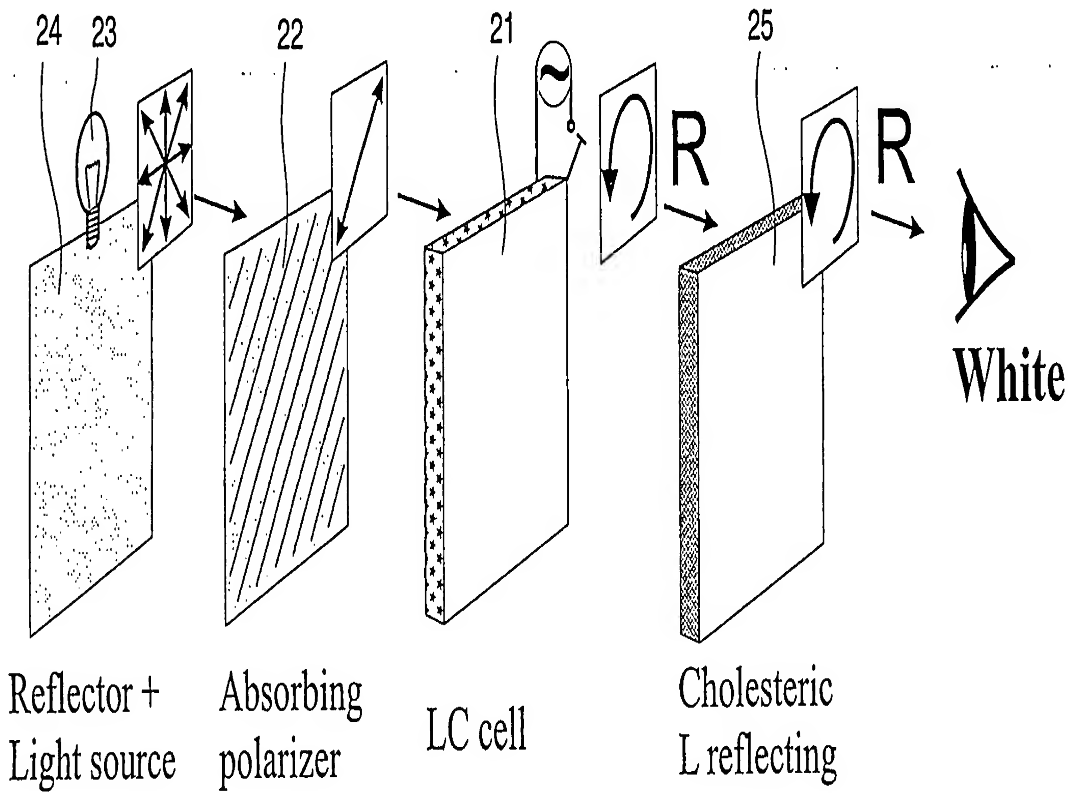

24
23
22
21
25
R
R
White
Reflector +
Light source
Absorbing
polarizer
LC cell
Cholesteric
L reflecting

Fig.6A

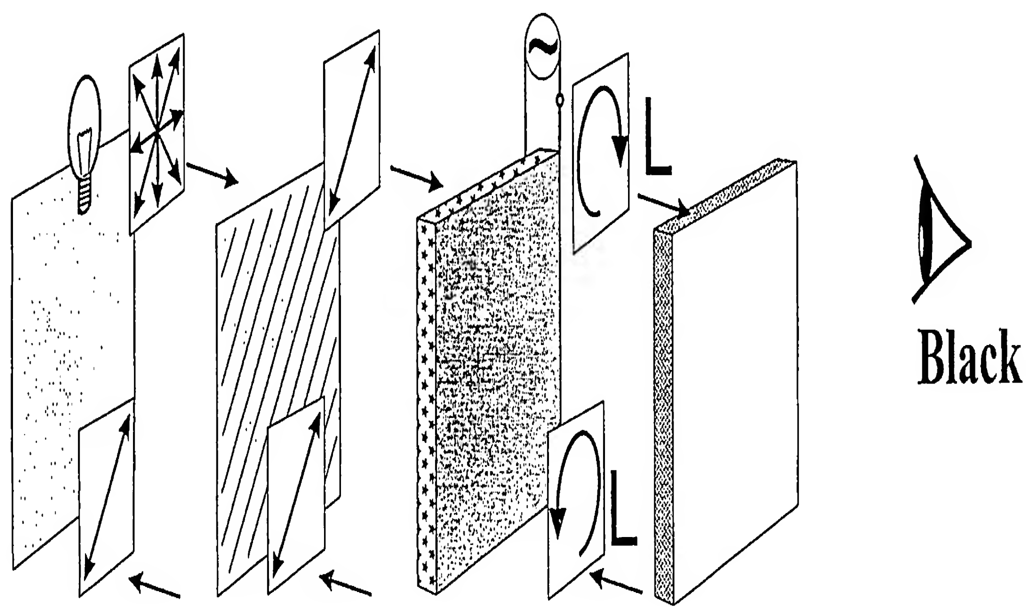

L
L
Black

Fig.6B

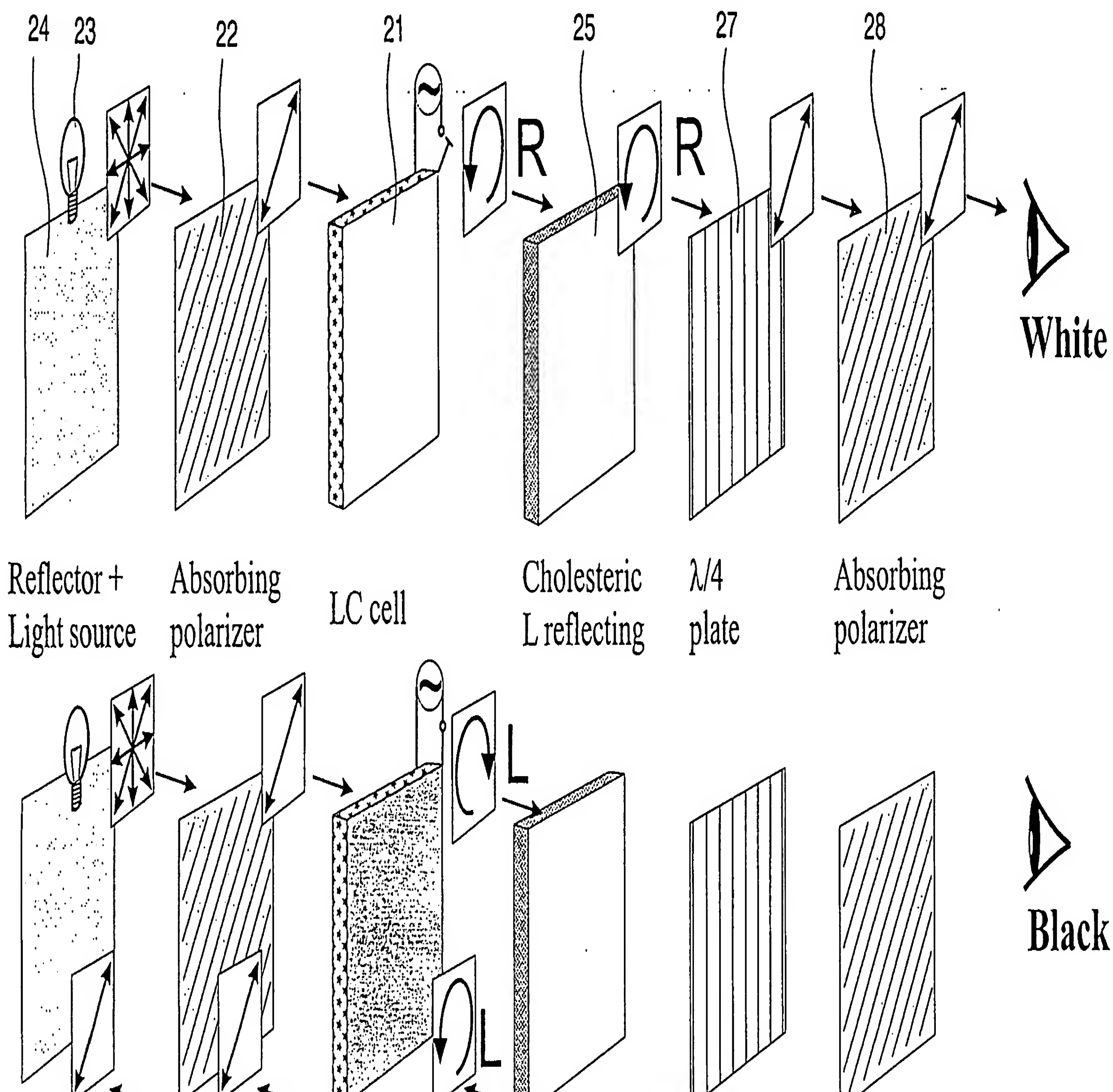

24
23
22
21
25
27
28
R
R
White
Reflector +
Light source
Absorbing
polarizer
LC cell
Cholesteric
L reflecting
λ/4
plate
Absorbing
polarizer
L
L
Black

Fig.7

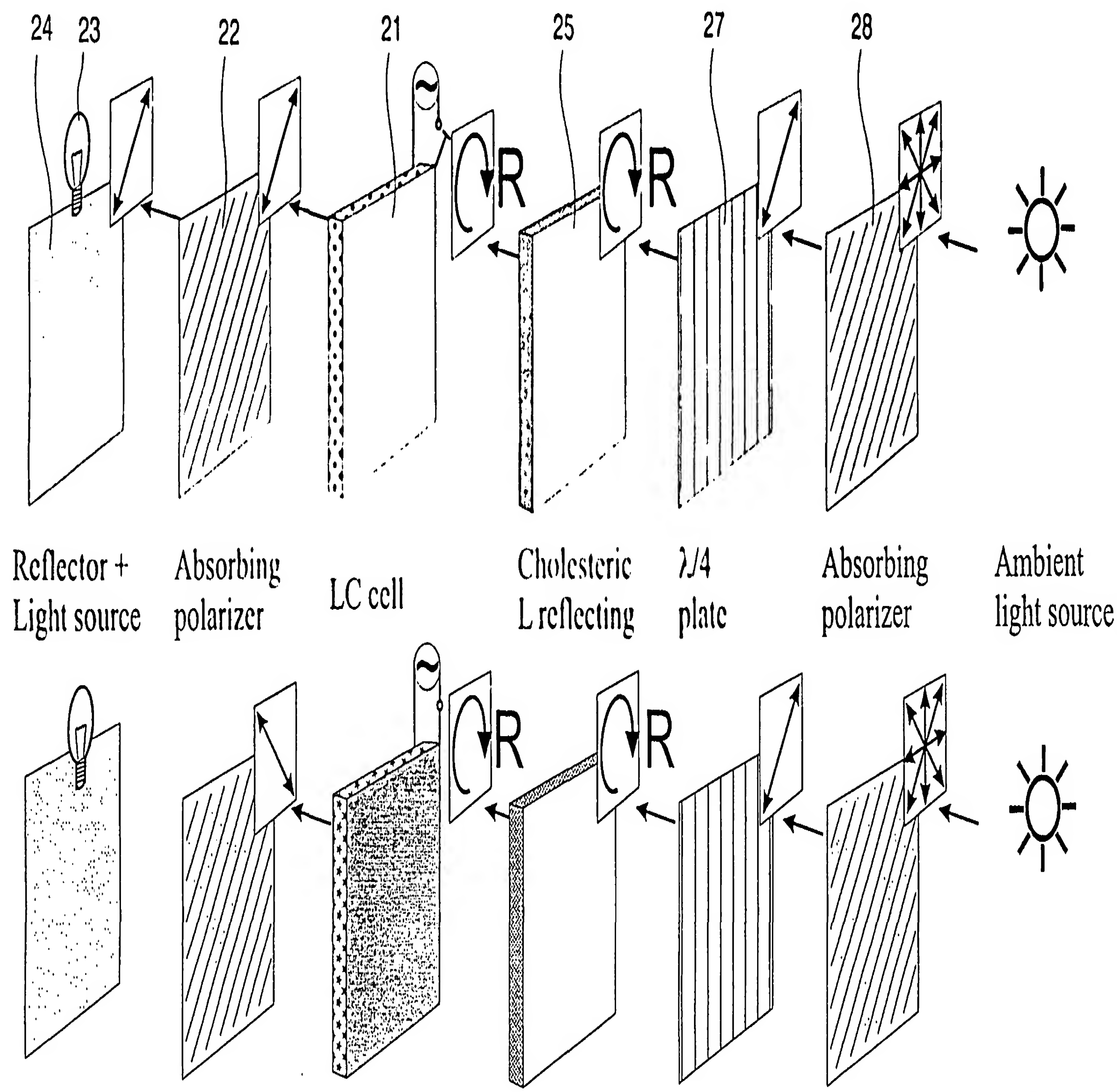

24
23
22
21
25
27
28
R
R
Reflector +
Light source
Absorbing
polarizer
LC cell
Cholesteric
L reflecting
λ/4
plate
Absorbing
polarizer
Ambient
light source
R
R

Fig.8

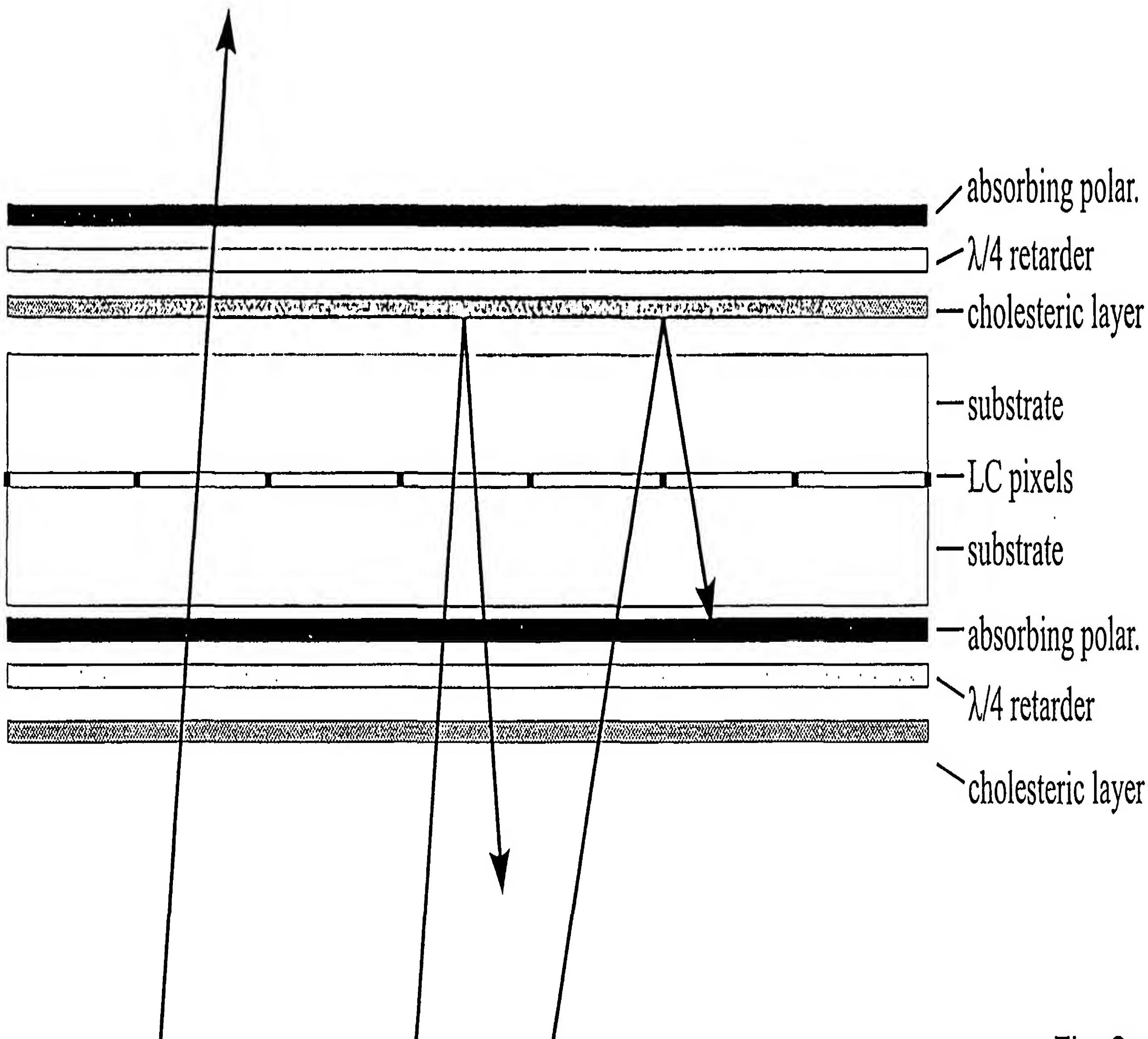

absorbing polar.
λ/4 retarder
cholesteric layer
substrate
LC pixels
substrate
absorbing polar.
λ/4 retarder
cholesteric layer

Fig.9

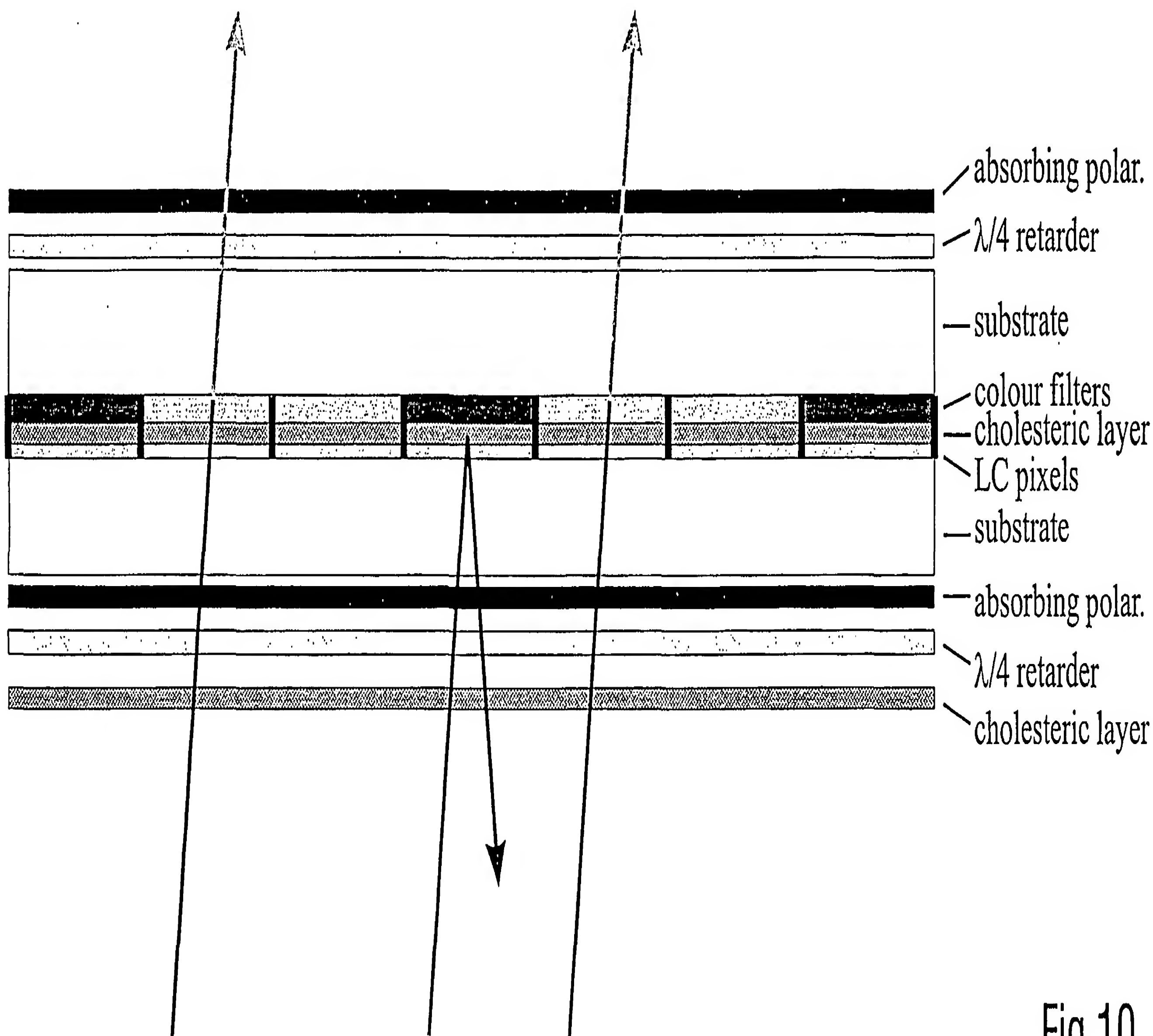

absorbing polar.
λ/4 retarder
substrate
colour filters
cholesteric layer
LC pixels
substrate
absorbing polar.
λ/4 retarder
cholesteric layer

Fig.10

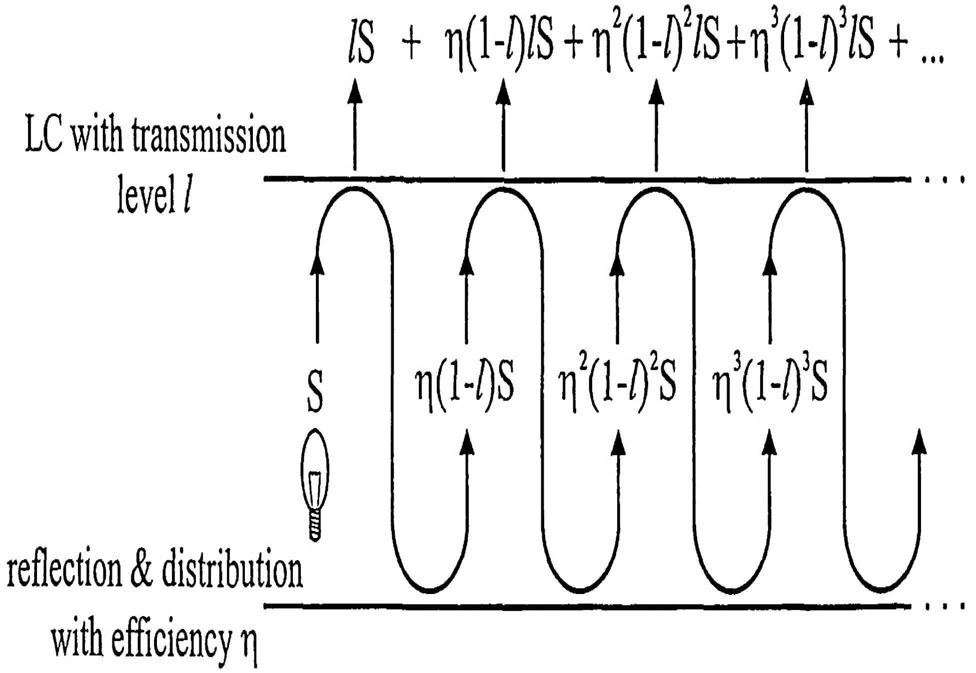

lS + η(1-l)lS + η²(1-l)²lS + η³(1-l)³lS + ...
LC with transmission level l
S
η(1-l)S
η²(1-l)²S
η³(1-l)³S
reflection & distribution with efficiency η

Fig.11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 02/03465

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 927 907 A (CITIZEN WATCH CO LTD) 7 July 1999 (1999-07-07) paragraphs '0027!-'0037!,'0044!,'0056! figures 1,6	1-7,12, 13
Y		14
X	WO 95 17691 A (MINNESOTA MINING & MFG) 29 June 1995 (1995-06-29) page 5, line 1 - line 28 page 12, line 16 - line 22 figures 2,3	1-3,5-7, 12,13
Y		14
X	EP 0 867 746 A (SEIKO EPSON CORP) 30 September 1998 (1998-09-30) column 6, line 17 - line 28 figure 3	1-3,5,8, 9
Y		14

☐ Further documents are listed in the continuation of box C

☒ Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 November 2002	14/11/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hauser, M

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 02/03465

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